Macro-Financial Architecture of Energy Ecosystems and Capital Trajectories

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Էներգետիկ էկոհամակարգերի և կապիտալի մակրոֆինանսական կառուցվածքը

Սարգսյան Հայկ Ա.
Տնտեսագիտության թեկնածու, դոցենտ,Ֆինանսական շուկաներ և ինստիտուտներ ամբիոն Հայաստանի պետական տնտեսագիտական համալսարան (Երևան, ՀՀ)

Ամփոփագիր. Ժամանակակից գլոբալ ֆինանսական համակարգը և էներգետիկ էկոհամակարգերը թևակոխել են վերափոխումների մի փուլ, որտեղ միկրոմակարդակի ֆինթեք նորարարությունները, կենտրոնական բանկերի թվային արժույթները և մակրոֆինանսական կայունության քաղաքականությունները առանցքային դեր են խաղում կանաչ անցման գործընթացում: Հետազոտության շրջանակներում համապարփակ կերպով քննարկվում են բանկ-ձեռնարկություն թվային ցանցերի ազդեցությունը վերականգնվող էներգիայի տեխնոլոգիաների զարգացման վրա, ինչպես նաև էներգետիկ շոկերի և բանկային դիվերսիֆիկացիայի ասիմետրիկ կապերը: Ուսումնասիրության առանցքում են մակրոտնտեսական կապիտալի ներդրումների ռեկորդային ցուցանիշները, առաջնային էներգետիկ մատակարարման կառուցվածքային տեղաշարժերը և ինստիտուցիոնալ անապահովության պայմաններում ձևավորվող էկոհամակարգերը: Միաժամանակ, վերլուծության են ենթարկվում զարգացած և զարգացող շուկաների միջև առկա կանաչ ֆինանսավորման բաշխման անհամաչափությունները և ինստիտուցիոնալ սահմանափակումները: Հետազոտության նպատակն է բացահայտել և համակարգված կերպով գնահատել, թե ինչպես են թվային ֆինանսական գործիքների, մակրոպրուդենցիալ քաղաքականությունների և էներգետիկ տեխնոլոգիաների փոխկապակցվածությունը նպաստում ֆինանսական կայունության ամրապնդմանը, վարկային ռիսկերի մեղմմանը, ինչպես նաև կայուն տնտեսությանն ուղղված կապիտալի արդյունավետ շրջանառության ապահովմանը: Աշխատանքում կիրառվել են համեմատական և էմպիրիկ վերլուծության մեթոդներ, որոնք հնարավորություն են տալիս հիմնավորել թվային ֆինանսների և էներգետիկ անցման ազդեցությունն դիմացկուն ֆինանսական համակարգերի ձևավորման գործում:
Հանգուցաբառեր և բառակապակցություններ՝ Ֆինթեք նորարարություններ, կանաչ էներգետիկ անցում, Կենտրոնական բանկերի թվային արժույթներ, էներգակիրների գների շոկեր, ինստիտուցիոնալ անհամաչափություն

Макрофинансовая архитектура энергетических экосистем и траекторий капитала

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Аннотация. Современная глобальная финансовая система и энергетические экосистемы вступили в фазу трансформаций, где микроуровневые финтех-инновации, цифровые валюты центральных банков и политика макрофинансовой стабильности играют ключевую роль в процессе зеленого перехода. В рамках исследования всесторонне рассматриваются влияние цифровых сетей «банк-предприятие» на развитие технологий возобновляемой энергетики, а также асимметричные связи между энергетическими шоками и банковской диверсификацией. В центре исследования находятся рекордные показатели макроэкономических капиталовложений, структурные сдвиги в первичном энергоснабжении и экосистемы, формирующиеся в условиях институциональной неопределенности. Одновременно анализируются диспропорции в распределении зеленого финансирования и институциональные ограничения между развитыми и развивающимися рынками. Цель исследования заключается в выявлении и систематической оценке того, как взаимосвязь цифровых финансовых инструментов, макропруденциальной политики и энергетических технологий способствует укреплению финансовой стабильности, снижению кредитных рисков, а также обеспечению эффективного

обращения капитала, направленного на устойчивую экономику. В работе использованы методы сравнительного и эмпирического анализа, позволяющие обосновать влияние цифровых финансов и энергетического перехода на формирование устойчивых финансовых систем.
Ключевые слова и словосочетания: Финтех-инновации, переход к зеленой энергетике, цифровые валюты центральных банков, ценовые шоки энергоносителей, институциональная асимметрия

Introduction. In today's rapidly evolving economic environment, financial architecture and energy ecosystems undergo profound transformation driven by digital finance and macro-financial stability frameworks. As global energy supply approaches 600 exajoules and clean investments reach milestone volumes, research focuses on the interplay between FinTech adoption, Central Bank Digital Currencies, banking stability, and structural transition impediments. Traditional systems have frequently struggled to optimize capital allocation and mitigate systemic vulnerabilities due to market frictions, information asymmetries, and energy price shock asymmetries. While studies examine clean energy technologies, research on harmonizing digital tools, banking diversification, and intermediation ecologies remains critical. Existing inquiries are often restricted to fragmented assessments, highlighting the need for robust interdisciplinary frameworks. Building upon these foundations, this study investigates the structural evolution of sustainable banking and macro-financial integration, examining their impact on system stability, credit accessibility, and capital flows. By analyzing empirical market drivers and macroeconomic energy trajectories, this research provides the framework necessary for policymakers and financial institutions to leverage digital and green financial innovations.

Research Methodology. This study adopts a rigorous methodology integrating a comparative analytical framework with qualitative insights and empirical trend evaluation to examine the structural evolution of sustainable banking, digital financial innovations, and green energy transition ecologies. The investigation centers on FinTech adoption, Central Bank Digital Currencies, macroeconomic energy supply dynamics, and systemic banking stability. To capture modern transformations, the research synthesizes extensive literature, policy documents, and empirical market data, incorporating recent benchmarks from the Energy Institute, BloombergNEF, and Statista. The framework relies on core economic theories of sustainable intermediation, technological resilience, and corporate transition financing, establishing a robust foundation for long-term banking stability.

Literature review. Wu (2026) investigates how FinTech drives renewable energy technology innovation among Chinese manufacturers (2010–2022). Utilizing patent and loan records, the study reveals a robust, nonlinear positive relationship, mediated by reduced financing constraints and lower R&D uncertainty, with varying impacts across firm scale, technological capacity, and ownership structures [**23**].

Unconventional monetary policy measures can effectively support the green transition. For instance, Zaghini (2024) demonstrates that the ECB's Pandemic Emergency Purchase Programme helps firms finance climate-friendly investments in bond markets [**25**], while Ferrari and Nispi Landi (2023) show that green-targeted quantitative easing reduces emissions and aids the shift toward a carbon-neutral economy [**9**]. Conversely, Gordo et al. (2024) find that monetary policy has exerted only a limited overall impact on renewable energy stocks since the rollout of quantitative easing [**11**].

Although central banks deploy macroprudential tools, climate stress tests, and disclosure frameworks, their integration into core monetary operations remains restricted [**5**]. Furthermore, D'Orazio and Popoyan (2023) observe that broader monetary policy mandates correlate with a greater adoption of climate-related financial policies, whereas more integrated financial stability governance structures do not show a similar relationship [**6, pp. 284-295**].

Yan et al. (2026) investigates the integration of molten salt thermal storage with circulating fluidized bed units to extend "banked fire" operations—a critical hot standby mode for managing grid peak loads. Thermodynamic modeling demonstrates that MSTS extends banked fire duration to six hours with 52.05% exergy efficiency, showing strong commercial viability with a 3.13-year payback period [**24**].

Meanwhile, Plikas and Kenourgios [**17**] examine renewable energy adoption and bank credit risk across 28 European economies from 2013 to 2022. Using OLS regressions, they show that renewable adoption stimulates economic growth, mediating borrower repayment capacities and lowering credit risk. Solar energy is particularly effective for risk reduction, though stabilizing impacts vary between core and peripheral nations depending on institutional quality and ESG integration.

Similarly, Saif-Alyousfi [**18**] examines nonlinear effects of energy price shocks on bank diversification across G7 economies using data from 13,225 banks (1992–2021). Applying a two-step

system GMM estimator, the study demonstrates that energy price fluctuations significantly reduce income and asset diversification. The relationship exhibits asymmetric dynamics—positive shocks hinder diversification while negative shocks can improve it—with smaller banks showing heightened vulnerability.

While early studies examine digital finance and energy efficiency [**23**], academic inquiry into Central Bank Digital Currencies remains scarce, often confined to theoretical modeling [**1, pp. 697-721**]. Prior work highlights CBDCs' core attributes like transparency and financial inclusion [**4, pp. 172-217**], alongside macro spillovers [**19**], but significant gaps remain in understanding how CBDCs drive urban energy efficiency. Consequently, an urgent need exists for a systematic interdisciplinary framework linking CBDC adoption to UEE, providing robust theoretical foundations and empirical insights for researchers and policymakers navigating modern financial-energy transitions.

Analysis. As synthesized in Table 1, the accompanying analysis examines the functional roles of sustainability transition intermediaries while contrasting institutional contexts across developed and developing economies.

N	Research Dimension / Focus	Core Literature & Conceptual Scope	Scientific Novelty & Key Insight
1	Ecology of Intermediaries	Kivimaa et al. (2019a, b) [**14, pp. 1062-1075; 15, pp. 110-125**]; Barrie & Kanda (2020) [**2, pp. 235-249**]; Soberón et al. (2022) [**20, pp. 127**]	Highlights the heterogeneous nature and "ecologies of intermediation", where actors complement, compete, or substitute to orchestrate sustainability transitions.
2	Transition Functions & Coordination	Kanda et al. (2024) [**13**]; Hyysalo et al. (2022) [**12, pp. 184-200**]	Emphasizes multi-domain roles ranging from coordination and knowledge exchange to strategic orchestration, while exposing capacity gaps in meeting all transition demands.
3	Developed Contexts Baseline	Kivimaa et al. (2019a) [**15, pp. 110-125**]	Identifies geographic bias in existing literature, predominantly centering on developed economies where specialized intermediaries perform functions.
4	Developing Context Constraints	Ghosh & Mguni (2025) [**10**]	Contrasts developed models with developing regions facing institutional insecurity, resource scarcity, and colonial path dependencies.
5	Power Asymmetries & Pathways	Kivimaa & Martiskainen (2018) [**16, pp. 83-99**]	Uncovers marked power asymmetries where certain actors command disproportionate authority, dictating how broader contexts shape technology and pathway support.

Table 1. *Multifunctional Intermediaries, Contextual Disparities, and Power Dynamics in Sustainability Transitions*

This comparison highlights how structural constraints, resource scarcity, and power asymmetries shape low-carbon pathways. Ultimately, it provides a vital conceptual lens for understanding how intermediation dynamics either accelerate or impede global sustainability transitions.

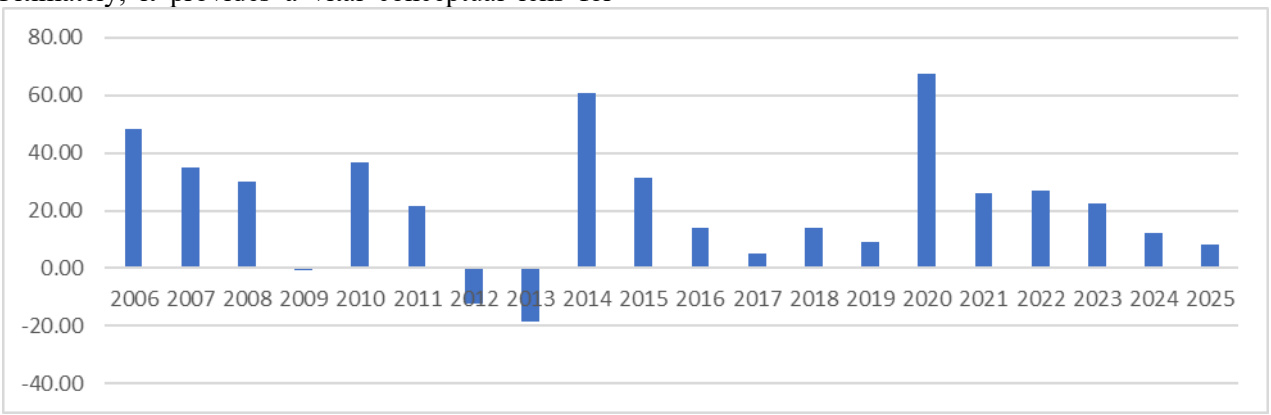

Figure 1. *Clean Energy Investments: Growth and Capital Trajectories (2006–2025)*

Bridging macroeconomic capital trends with micro-level financial mechanisms is essential, as tracking aggregate investments—such as the record $2.3 trillion reached in 2025 (BloombergNEF,

2026)—remains insufficient without evaluating structural allocation frictions. By synthesizing macro-trajectories with banking stability and institutional intermediation, this study uncovers why capital remains concentrated in mature sectors like solar energy. Ultimately, these insights illuminate critical funding gaps for emerging technologies and provide policymakers with a robust framework to align financial markets with climate targets.

Figure 1 illustrates the annual growth rate and capital trajectory of global clean energy investments from 2006 to 2025 [**3**].

The chart captures the dynamic fluctuations in investment growth over the two decades—ranging from cyclical contractions in earlier periods to a sharp peak surge of 67.47% in 2020—culminating in a record-breaking global investment volume of $2.3 trillion in 2025 with an annual growth rate of 8.1%.

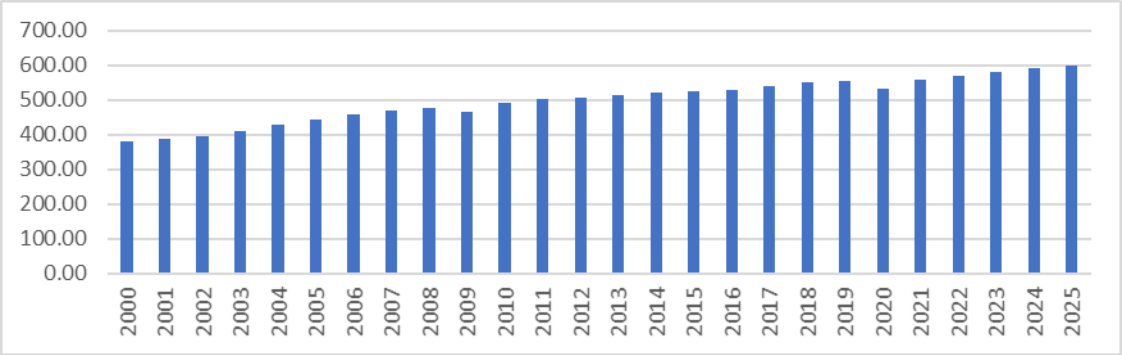

Figure 2. *Global Primary Energy Supply Trajectory and Structural Fuel Dynamics (2000–2025)* [**7**]

Figure 2 illustrates the long-term expansion of the global energy supply from 2000 to 2025, reaching approximately 600 exajoules in 2025 with an annual growth rate of roughly one percent (Energy Institute, 2026). The data reveals a highly resilient upward trajectory interrupted only by major macroeconomic shocks, such as the 2009 global financial crisis and the 2020 pandemic-induced contraction.

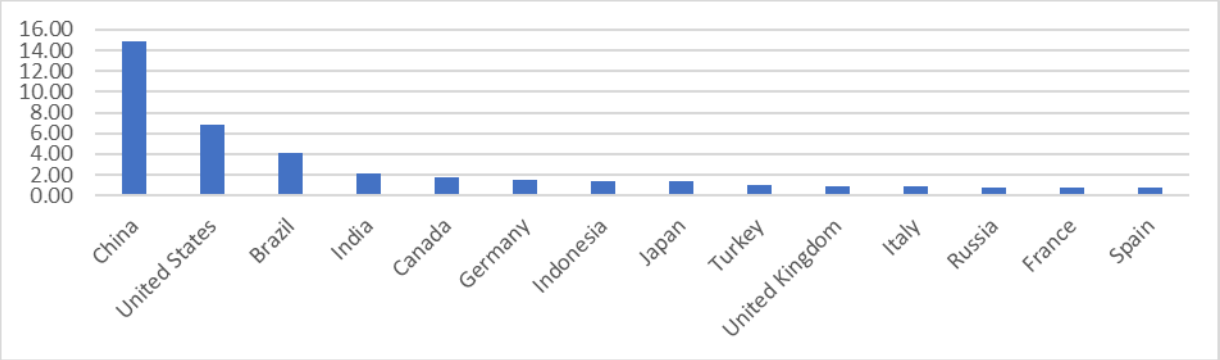

Figure 3. *Leading countries by renewable energy consumption worldwide in 2025 (in exajoules)*

While fossil fuels (oil, coal, and natural gas) continue to dominate primary consumption—each exceeding 140 exajoules—the concurrent doubling of clean energy investments since 2014 signals a critical structural shift. By integrating Figure 2 into our analytical framework, this study connects macroeconomic energy supply expansion with micro-financial transition mechanisms, highlighting the dual challenge of meeting rising global energy demand while accelerating decarbonization pathways across diverse institutional contexts.

Figure 3 highlights the global distribution of renewable energy consumption across leading nations in 2025, led by China with 14.91 exajoules and followed by the United States [**8**].

The data captures how diverse renewable sources—including wind, solar, geothermal, and massive hydroelectric infrastructure—power these dominant economies. By integrating Figure 3, this study bridges macro-geographic disparities with micro-financial adoption patterns, illustrating how institutional scale, national energy goals, and regional policy frameworks influence the uneven global transition toward low-carbon systems.

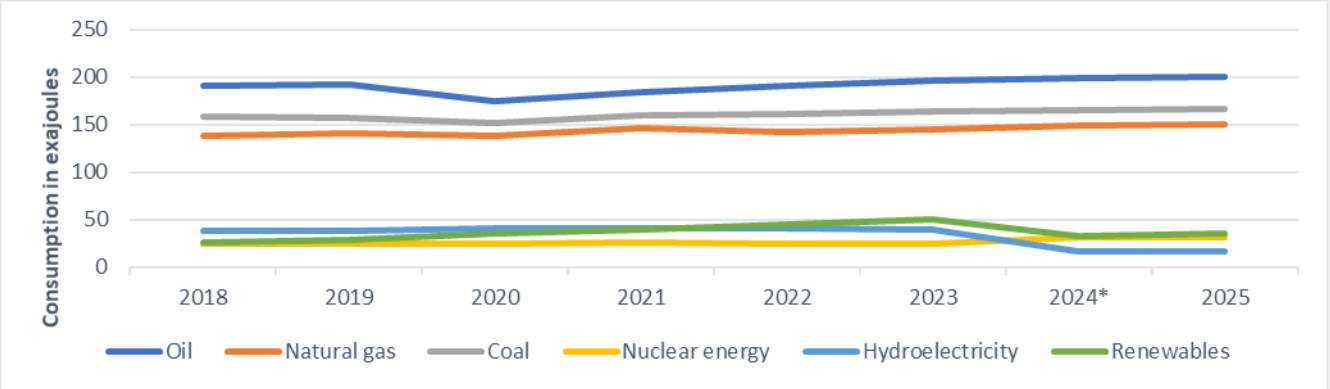

Figure 4. Energy Supply Worldwide from 2018 to 2025, by Fuel Type (in Exajoules)

Figure 4 details the disaggregated global energy supply trajectory by fuel type from 2018 to 2025, highlighting the persistent dominance of fossil fuels alongside the evolving scale of clean energy sources. The data reveals that oil remains the most consumed primary fuel, reaching approximately 200.97 exajoules in 2025, while coal and natural gas continue to maintain substantial consumption baselines above 140 exajoules.

Concurrently, non-fossil and renewable vectors exhibit progressive structural scaling, though stark divergences remain among sub-categories such as hydroelectricity and broader renewables. By integrating Figure 4 into our interdisciplinary framework, this study bridges macro-level fuel mix dynamics with micro-financial transition barriers, illustrating why targeted green financing and policy interventions are essential to accelerate structural decoupling from carbon-intensive baselines.

Figure 5 illustrates the global installed electricity capacity by energy source in 2024, revealing that fossil fuels maintain a leading capacity of 4,757 gigawatts, closely followed by renewables at 4,422 gigawatts.

A disaggregation of renewable vectors highlights solar energy as the largest contributor with 1,863 gigawatts, followed by hydroelectricity (1,230 GW) and wind power (1,133 GW). Integrating Figure 5 into our interdisciplinary framework bridges macro-level power generation capacity disparities with micro-financial investment constraints, emphasizing how structural capital reallocation is required to scale clean energy. Building on this, the study synthesizes a framework bridging micro-financial innovations, engineering solutions, and macro-financial stability. It elucidates how digital finance alleviates financing constraints and accelerates renewable innovation.

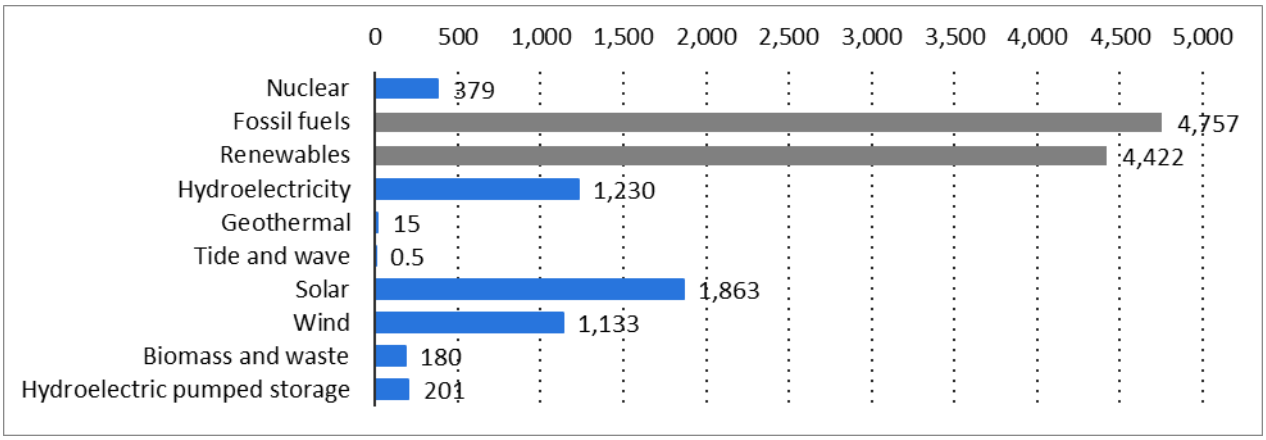

Figure 5. *Installed electricity capacity worldwide in 2024, by source (in gigawatts)* [**21**]

Concurrently, monetary policies facilitate transition investments, while energy price shocks exert asymmetric pressures on banking diversification, disproportionately impacting smaller institutions. Furthermore, connecting Central Bank Digital Currencies with urban energy efficiency enhances sustainability, revealing severe institutional disparities across developing economies.

Conclusions. This study provides a comprehensive interdisciplinary framework examining the intricate nexus between digital financial innovations, macro-financial stability, and the global clean energy transition. By synthesizing micro-level mechanisms—such as FinTech-driven

bank-enterprise networks and Central Bank Digital Currencies—with macro-level capital trajectories, the analysis demonstrates that digital financial tools are instrumental in alleviating R&D uncertainties and corporate financing constraints for renewable energy technology innovation. Furthermore, the research highlights that while clean energy adoption fosters macroeconomic growth that mitigates bank credit risks, energy price shocks exert non-linear, asymmetric pressures on banking sector diversification, disproportionately impacting smaller institutions. The integration of empirical data from 2024–2026 reveals profound structural disparities in capital allocation. Although mature clean energy sectors in developed economies experience rapid scaling, developing regions face severe institutional insecurity and power asymmetries. Consequently, aligning financial architectures and macroprudential policies is vital for accelerating global decarbonization.

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